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ARTILLERY METEOROLOGICAL ANALYSIS OF PROJECT PASS

By

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The Atmospheric Sciences Laboratory, US Army Electronics Command, conducted a comprehensive experiment in ballistic meteorology during November-December 1974 at White Sands Missile Range. The purpose was to determine what improvement might be made in the representativeness of meteorological messages furnished to artillery batteries by collecting all meteorological data available in a corps size area, performing a relatively simple analysis, and disseminating the results to the batteries. One thousand rounds of 8-inch howitzer ammunition were next page

20. Abstract (cont)

fired over a 5-week period with concurrent meteorological data taken at eight sites on the Missile Range. The most striking feature of the results is the relatively small deviation in predicted impact (less than 40 m range sigma) due to meteorological error in 85% of the 79 firing series analyzed.

CONTENTS

INTRODUCTION

The accurate assessment and application of atmospheric wind, temperature, and pressure are well-known essentials to effective delivery of artillery munitions. The belief that meteorological errors are major contributors to the total delivery error budget is widely held and is supported by many previous studies of the problem [1]. These errors may be broadly categorized as instrumental and environmental. Environmental meteorological errors in this context are defined as those arising from the separation in time and space between measurement and application.

The Atmospheric Sciences Laboratory (ASL) is conducting studies designed to minimize the above meteorological errors. As part of these studies, a field experiment (PASS - Prototype Artillery Subsystem of the Automatic Meteorological System) involving actual howitzer firings together with meteorological data collection at several sites on White Sands Missile Range (WSMR) was conducted during November-December 1974. This report addresses the analysis of the ballistic meteorology data from that experiment, the results thereof, and their implications. A brief description of the experimental setup is included for completeness. A comprehensive description is available under separate cover [2].

APPROACH

The main purpose of the ballistic meteorology portion of the PASS experiment was to test the hypothesis that an analysis of the upper air soundings available from five to six meteorological sections (the assumed usual number in a type corps) could substantially reduce the contribution of meteorological errors to the total delivery error budget. Relatively simple objective analysis algorithms were chosen as the vehicle for combining the multiple soundings since the computation time and computer core storage available for the purpose are limited for field application.

To compare the merits of several competing algorithms via a firing experiment, two general procedures for the experiment are feasible. One would be to identify a number of "most promising" algorithms in advance and conduct a series of firings at the same target by using each algorithm in turn to produce a meteorological message for the firing problem solution. The algorithm giving the smallest dispersion about the target center would be considered the "best" of the group. To gather a sufficiently large sample for statistically significant results in this manner would require a prohibitive amount of ammunition and time for even a small number of candidate algorithms. The second approach would be to conduct a series of firings at the same aiming point by using any reasonably accurate meteorological message in the firing problem solution. Thus, the range to impact should not vary enough from series to series to cause significant changes in unit wind effects, unit muzzle velocity effect $\frac{(\partial R)}{\partial Mv}$, and so on. Then by redefining the mean point of impact of each series as the target center for that series, computer trajectory

simulations could be examined to determine the relative ability of any number of candidate algorithms to predict the observed mean point of impact (Figure 1). The algorithm yielding the smallest dispersion about the observed mean impact points would then be the "best" of those examined. This second approach was chosen for the PASS experiment since (1) it was considerably more economical in materials and time, and (2) it was not certain that the most promising objective analysis algorithms had been identified.

To further clarify the approach taken, suppose that a given series is fired and the mean point of impact is 75 m over the nominal range to the aiming stake and 35 m to the right (Figure 1). Suppose also that the muzzle velocity, firing angles, and other nonmeteorological variables of this series were accurately measured. Then any meteorological message (together with the measured hardware variables of this series) which produces a simulated mean impact point identical to the actual impact point may be regarded as the most desirable meteorological message for that series.

It is recognized that the transformation (via the ballistic equations of motion) of zonewise variables of pressure, temperature, and wind components into an impact point represents a transformation from E_n to E_2 ($n > 2$) and is not unique in this case. However, if a meteorological algorithm leads to simulated impacts consistently closer to actual impact (i.e., smallest dispersion) than the other candidate algorithms, and if this is a statistically significant result, then it may be concluded that the best algorithm of the group has been isolated.

EXPERIMENT DESCRIPTION

Two 8-inch howitzers were emplaced on the Missile Range, and a well-qualified crew from Fort Sill fired them into an impact area which was cleared and leveled for several hundred meters around the aiming stake. The firings were comprised of 8-round series (10 rounds for the first series of the day), 2 minutes between each round, 1 hour between each series. The experiment spanned 20 days (not necessarily consecutive). Guns were alternated daily whenever possible, with the number of series fired each day varying from 4 to 10.

Impact locations for each round were determined by triangulation from three flash ranging stations placed symmetrically around the aiming stake [3]. Muzzle velocity of each round was obtained from a Doppler velocimeter supplied and operated by WSMR.

Upper air soundings were taken at ten sites during the experiment, but only eight of these were intended for use in the ballistic analysis (see map [Figure 2] and Table 1 for relative locations). Five stations simulating the meteorological sections in a type corps released balloons simultaneously each 2 hours, beginning 1 hour and 15 minutes before the first series of the day. The remaining three stations released simultaneously 1/2 hour after the first five. The above measurements were

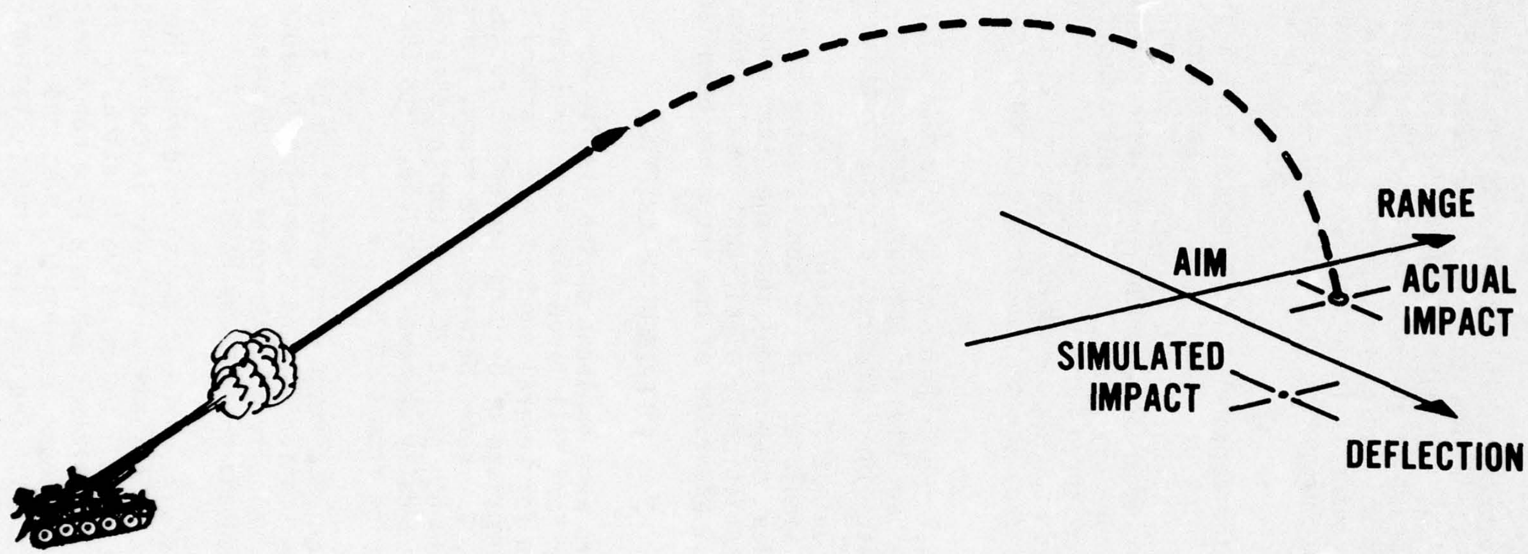

Figure 1. Pass statistical analysis.

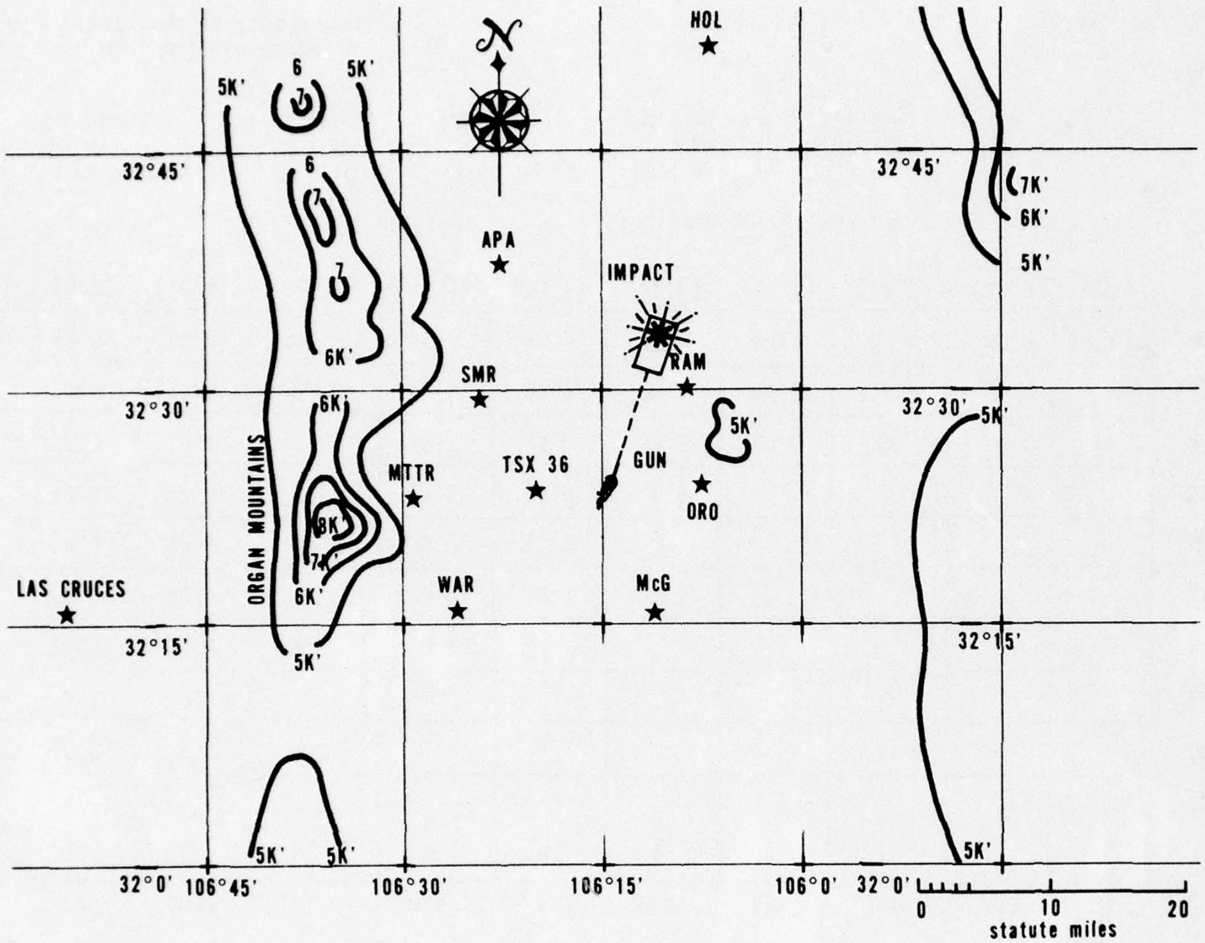

Figure 2. Approximate map of artillery meteorological sections, gun position and impact area for artillery meteorological comparisons by USAECOM Atmospheric Sciences Laboratory at White Sands Missile Range, Nov 74.

TABLE 1. DISTANCE BETWEEN RAWINSONDES OR SIMULATED ARTILLERY METRO

DISTANCE BETWEEN RAWINSONDES

(kilometers)

SECTION	TSX*	ORO*	LSC	MCG*	WAR*	MTR	SMR*	RAM	APA	HMS	
	1	2	3	4	5	6	7	8	9	10	
1. LC-36*	0										TSX
2. Orogrande*	16.5	0									ORO
3. Las Cruces†	57.5	73.6	0								LSC
4. McGregor*	19.5	15.6	68.0	0							MCG
5. War Road*	16.5	28.7	47.2	20.8	0						WAR
6. MTTR†	16.4	33.0	41.7	32.3	15.9	0					MTR
7. SMR*	12.1	27.0	51.5	31.5	21.9	10.9	0				SMR
8. Rampart	18.3	10.7	75.0	25.7	34.0	33.2	24.4	0			RAM
9. Apache	24.5	33.0	62.6	43.0	37.9	26.2	16.2	25.0	0		APA
10. Holloman	53.8	49.6	100.3	65.0	70.2	62.6	51.7	39.4	37.8	0	HMS
(Gun Site)	(6.2)	(10.4)	(63.5)	(16.2)	(20.3)	(22.6)	(17.4)	(13.7)	(26.9)	(51.7)	

	All Stations			Simulated Corps Stations		
Mean Distance	23.2 mi	=	37.3 km	13.1 mi	=	21.1 km
Minimum	6.6 mi	=	10.7 km	7.5 mi	=	12.0 km
Maximum	62.3 mi	=	100.3 km	19.6 mi	=	31.5 km

*Indicates those used in simulated corps.
†Indicates those omitted from ballistic analysis.

obtained by using a rawinsonde with standard AN/GMD-1B tracker, and computer meteorological messages were prepared in standard artillery fashion [4]. Wind-only profiles were obtained each hour at all eight stations by modified T-9 radar equipment, coincident with the rawinsonde measurements every second hour. The winds were incorporated into separate computer meteorological messages utilizing either concurrent or 1-hour-old GMD determined pressures and temperatures as appropriate. The howitzers, meteorological stations, aiming stake, flash ranging positions, and velocimeter antenna were all located by survey crews furnished by WSMR. Coordinates were given in Universal Transverse Mercator (UTM), White Sands Transverse Mercator (WSTM), and White Sands Cartesian System (WSCS). WSTM was selected for use in the analysis.

The procedure of laying the howitzer for any given series of rounds was predicated solely on the range safety requirement of impacts well within the cleared zone designated as the impact area, so that the coordinates of the center of this area represented the aiming point or "target" so far as the Fire Direction Center (FDC) was concerned. For more details, see [2].

EXPERIMENTAL ERROR

The major variables of importance to the ballistic meteorology analysis are, series by series:

1. The meteorological data

2. The mean fall-of-shot location

3. The quadrant elevation and azimuth angles

4. The mean muzzle velocity

5. Projectile weight

6. The exterior ballistics parameters of the projectile (drag coefficient, etc., assumed to be identical for identical projectiles)

Of these, the last is assumed to be subject to bias error only, while both bias and random errors may occur in the other five.

Several tedious hand editing passes through the "raw" meteorological data by separate groups within ASL have revealed numerous errors of presumably human origin in the temperature and pressure values, with subsequent influence on the wind determination at those points; but this has not proven to be a significant problem to the ballistic analysis. The smoothing inherent in averaging over height layers several hundred meters thick plus the smoothing inherent in the ballistic equations of motion tends to minimize random errors of both instrumental and human origin. In fact, the meteorological data used in the ballistic analysis is

identical to that collected in the field with the exception of a visual inspection of the computer meteorological messages for obvious spike errors in the temperature and pressure profiles. Errors of this type could and should be easily detectable by competent military personnel in the field.

The location of the impact point of each round was examined, and those rounds wherein the error was considered excessive were discarded. This procedure occasionally caused an entire series to be discarded. The total losses were few and were caused by commencing the day's firings just before dawn when the flash rangers had difficulty seeing the burst point. A detailed treatment of this portion of the experiment is given in [3], but essentially the impact locations retained for analysis should be accurate to ±10 m.

Firing angles were set into the howitzers by the gun crew referencing a surveyed orienting line for azimuth and checking the quadrant elevation setting with a gunner's quadrant. Since the howitzer had to be depressed to load, the elevation angle was set and checked for each round, but the azimuth laid was checked only after completion of the series. Twenty projectiles, selected at random and weighed, proved to be well within tolerance of their four-square weight. Twenty powder bags (charge 7 white) were also weighed with similar results. The projectiles and charges were from the same lot, respectively. The firing crew were extremely careful in loading, using the hydraulic ram for all but a few rounds, and employing a gauge to insure that the charge was always placed in the same position in the breech. Further, the charge stack was sheltered on three sides and the top from the sun and wind, with propellant temperatures recorded at one top and one bottom corner of the stack. These two temperatures were averaged to obtain the propellant temperature used to solve the firing problem.

The measurement of muzzle velocity was the most difficult of the required variables. The velocimeter was emplaced approximately 100 m behind the guns, with a less than optimum look angle. The method of reducing the data to muzzle velocity used in the first few days of the experiment was the same as that used to determine rocket velocity, which reaches its maximum at a relatively large distance from the launcher. The results were therefore more indicative of radial velocity component than total velocity and were too low. When notified of this error, the velocimeter branch derived and applied corrective factors (to account for the unsatisfactory geometry) which subsequent analysis has shown to be of completely acceptable accuracy and the best of several other means investigated for transforming radial velocity to true velocity. The precision of the velocimeter data is excellent, as evidenced by extremely high correlation between the round-to-round difference in measured muzzle velocity and the round-to-round difference in range components of impacts, both before and after the corrective action to reduce the bias.

ANALYSIS

The objective of the data analysis was to isolate the effect of errors in ballistic meteorology on the impact points of the projectiles and to examine some methods of reducing the error. The procedure is best illustrated by the following set of linearized ballistic equations. Only the range component of impact location will be shown, but analogous equations for the cross component are easily written. Let the true mean range to impact (R) for a given series be represented by:

$$R = R_N + \Delta V + M + \text{NEGLIGIBLE TERMS} \qquad (1)$$

where R_N is the nominal range which would be reached at the true quadrant elevation angle if muzzle velocity and meteorology effects are standard. ΔV and M are the true range displacements from R_N (in meters) due to nonstandard muzzle velocity and nonstandard meteorological conditions. The negligible terms include nonlinear or second order effects of smaller magnitude.

The relevant quantities in Eq. (1) measured (or calculated) during the experiment are subject to error and may be written as:

$$R_M = R + \varepsilon_R$$

$$R_{N\theta} = R_N + \varepsilon_\theta$$

$$\Delta V_M = \Delta V + \varepsilon_V$$

$$M_A = M + \varepsilon_A \qquad (2)$$

The various errors are ε_R, due to imprecise location of fall-of-shot; ε_θ, due to quadrant elevation error and written as an effector of nominal range; ε_V, due to measurement error in muzzle velocity; and ε_A, due to departure from the "true" meteorology of a meteorological message derived with algorithm A, containing instrumental error, algorithm error, and natural space-time variability. The errors are assumed to be random from series to series, to be drawn from populations of zero mean with variances characteristic of the PASS experiment, and to be statistically independent.

Ballistic trajectory simulations were made series by series by utilizing the series mean measured muzzle velocity, quadrant elevation angle, azimuth angle, standard (four squares) projectile weight, and various meteorological messages produced by the competing meteorological analysis

algorithms. Expressing the simulated impact range in the simple linear fashion of Eq. (1):

$$R_A = R_{N\theta} + \Delta V_M + M_A \tag{3}$$

Subtracting Eq. (3) from R_M

$$\Delta_A = R_M - R_A \tag{4}$$

From Eqs. (2) and (1):

$$\Delta_A = - \varepsilon_\theta - \varepsilon_V + \varepsilon_R - \varepsilon_A \tag{5}$$

Lumping the nonmeteorological terms together and labeling the sum "experimental error,"

$$\Delta_A = \varepsilon_{EXP} - \varepsilon_A \tag{6}$$

The variance of $\Delta_A (\sigma^2_{\Delta A})$ is a measure of the performance of meteorological algorithm "A" in reproducing the observed impacts. This is subject to the assumption that the estimators of meteorological displacement are unbiased estimators ($\overline{\Delta}_A = 0$); otherwise, a better measure might be the RMS Δ_A. Further, it is meaningful to compare $\sigma^2_{\Delta A}$ and $\sigma^2_{\Delta B}$ for algorithms "A" and "B" to discover if any statistically significant difference exists and, if so, which is better (smaller).

The meteorological algorithms to be tested on the PASS data were limited to three, hereafter designated as Methods I, II, and III. Method I is the single station technique currently in use by the Field Artillery [4]. Methods II and III were selected from a group of candidate objective analysis schemes based on comparisons between estimates of ballistic meteorology messages given by the schemes and by an actual sounding at the place and time of estimation. The candidate group was by no means an exhaustive collection of available objective analysis techniques. The initial screening criteria to form the group were based principally on simplicity. The two methods selected from the group will be defined and briefly discussed in this report, but a more complete discussion including the other candidates is given in [2].

METHOD I

The station designated "TSX" (Figure 2) was selected as the Method I station. It was the closest to the howitzers and therefore the most likely to be chosen by a commander in the field to provide computer

meteorological messages for his battery. The soundings were taken according to standard artillery meteorological methodology [4] through line 9 (4000 m AGL). This practice was followed at all stations.

METHOD II

This algorithm takes the form (suggested by Barnett, ASL) of a linear predictor, or "weighted average,"

$$\hat{A} = \Sigma \alpha_i A_i$$

where

$$\Sigma \alpha_i = 1$$

and

$$\alpha_i \propto 1 \Big/ \left(c_1 d_i^{\frac{1}{2}} + c_2 t_i^{\frac{1}{2}} \right)$$

(all summations taken over the five "corps" stations). A_i is a measured meteorological message parameter of interest (wind component, pressure, or temperature) at the i^{th} station; the weights α_i are inversely proportional to a function of the distance (d_i) and time (t_i) separation between measurement and application (station location and time of release); and $\hat{A}$ is the estimate of the parameter. The weighting was performed zonewise, with no dependence on zones above or below.

The intuitive appeal of this particular estimator is better illustrated by considering that the weights should be proportional to the confidence that the measured parameter represents the actual parameter at the time and place of application. Other investigators [5] have described atmospheric time-space variability in the following manner:

$$\sigma_d = c_1 d^{\frac{1}{2}} \text{ (variability over distance d),}$$

$$\sigma_t = c_2 t^{\frac{1}{2}} \text{ (variability over time interval t).}$$

These relationships then give rise to the Method II estimator form. The value of c_1 was obtained from space variability data furnished by personnel of the US Army Ballistics Research Laboratory (BRL) using a least squares fit [6]. The value for c_2 was then obtained from $c_1 = c_2/\sqrt{30}$, i.e., a distance of 30 km gives equal variability to a time separation of 1 hour. This represents a compromise between reported variability

equivalences of as much as 46 km/hr to as little as 12 km/hr. The specific values are:

$$c_1 = 0.47$$

$$c_2 = 0.3189,$$

distance in kilometers, time in minutes.

METHOD III

Although Method II has a time dependent term, it is in no way intended to extrapolate time (or space) trends to the time and place of firing. Method III is an attempt to detect both time and space trends and extrapolate to the applicable location and time.

At each station, the meteorological message was extrapolated to the time of firing according to the following rules:

1. If only one message was present in the data bank for a station, persistence was invoked (no change).

2. If two messages were available for a station, a linear trend was extrapolated to the firing time, the average of the two messages was calculated, and finally the mean of the linear trend value and the average value was obtained.

3. If more than two messages were available from a station, the procedure was identical to step 2 except that a cubic spline was fit to the data points instead of the linear trend.

The procedure was done zonewise for each station; and in all cases analyzed, the requirement was invoked that the most recent release at a station would be no more than 135 minutes before firing time or the station would be ignored.

Having obtained a message at each station extrapolated forward to a common time, the next step was to fit a least squares plane to the data in space and evaluate the plane at the howitzer location, thus

$$\hat{A} = ax + by + c.$$

$\hat{A}$ is the estimate of a meteorological parameter; x and y are the howitzer coordinates; and a, b, and c are determined from the least squares fit over the stations. A plane was fit for each atmospheric zone and for each parameter of interest (wind components, pressure, and temperature).

RESULTS

After editing for fall-of-shot location errors, velocimeter dropouts, etc., the original 115 firing series were reduced to 79 which were suitable for analysis. Table 2 summarizes the analysis of the 79 cases. The data were partitioned into a set of 68 cases labeled "normal" and a set of 11 cases labeled "special" when it was noticed that relatively few of the cases gave large errors. The selection of 100 m range miss-distance as the partition was not entirely arbitrary, since the miss-distance frequency histogram indicates a bimodal distribution with the point of overlap of the modes being approximately 100 m. Figure 3 represents the same data as Table 2 but in graphical form.

There are two major features of the results in relation to the objectives of this experiment. First, an attractive decrease in ballistic meteorology error failed to materialize for the algorithms tested. When it is recalled that experimental error is of necessity included in the results, it is apparent that no algorithm will offer much improvement in the "normal" set, since the meteorological error is already small. An examination of all the experimental data inputs leads to the conclusion that time trends in the meteorological regime produced the "special" set of 11 cases of large miss-distance. Figures 4 and 5 illustrate time-trending winds on 2 of the days where 100 m range misses were indicated by the simulation. The meteorological message zone 5 (1500-2000 m AGL) vector winds reported by all operational stations are depicted (vector origin at station) and at times exhibit distinct changes in speed and/or direction occurring over time periods of the order of 2-3 hours. These changes are in the proper direction and of the approximate magnitude to produce the observed miss-distance in range, while leaving the deflection miss-distance relatively small. The orientation of the gun-target line to the prevailing winds (westerly) during the test coupled with the general tendency of the time trends to proceed from crosswind to head wind produced the greatest error in the range component of impact. This is most likely an accidental circumstance peculiar to the PASS experiment. It remains possible then to effect significant improvement in meteorological error for these cases, although Method III failed to do so.

Second, the low percentage (15%) of the very difficult "special" cases is itself interesting. Similar experiments made by other investigators at different locations and seasons [7,8] corroborate this percentage, indicating that the meteorological conditions encountered during the PASS experiment were neither abnormally quiet nor noisy. The frequency of occurrence of time trending meteorological situations is obviously a strong function of season at a given place, but the quirks of local climatology preclude any general statement about the functional dependence on latitude or other purely geographical variables.

The space variability depicted in Figure 6 was computed by using Method I for each station in turn. The stations known as McGregor (MCG) and WAR (Figure 2) were situated to the east of the southern end of the Organ Mountains and are believed to have been adversely affected by the disturbance of the prevailing westerly flow around the mountain. The time

TABLE 2. COMPARISON OF RESULTS FOR METHODS I, II and III

Total of 79 Cases Analyzed
(1-2 hr GMD)

Actual - Simulated

Range (m) $\overline{\Delta R}$	$\sigma\Delta R$	Meteorological Message	Deflection (m) $\overline{\Delta D}$	$\sigma\Delta D$
-13	69	Method I	9	36
-27	63	Method II	10	33
-21	63	Method III	12	33

Partitioned Statistics from PASS
(1-2 hr GMD)

Actual - Simulated

Method	Partition	No. of Series	Range (m) $\overline{\Delta R}$	$\sigma\Delta R$	Deflection (m) $\overline{\Delta D}$	$\sigma\Delta D$
I	Special	11	-130	98	-11	31
	Total	79	-13	69	9	36
	Normal	68	6	38	12	36
II	Special	11	-132	91	-5	30
	Total	79	-27	63	10	33
	Normal	68	-9	35	12	33
III	Special	11	-127	93	0	29
	Total	79	-21	63	12	33
	Normal	68	-4	35	13	44

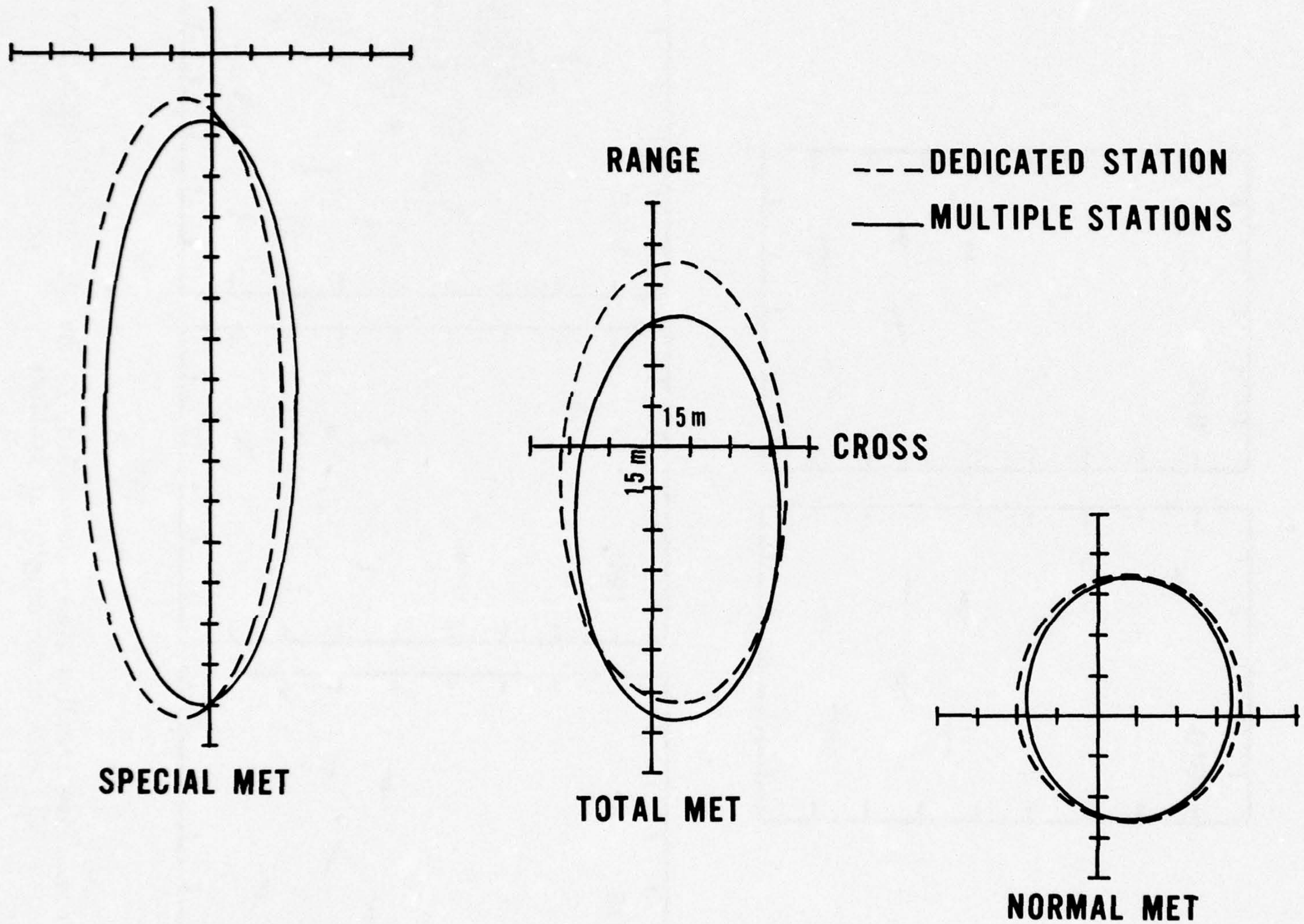

Figure 3. One probable error difference eclipse (actual - simulated).

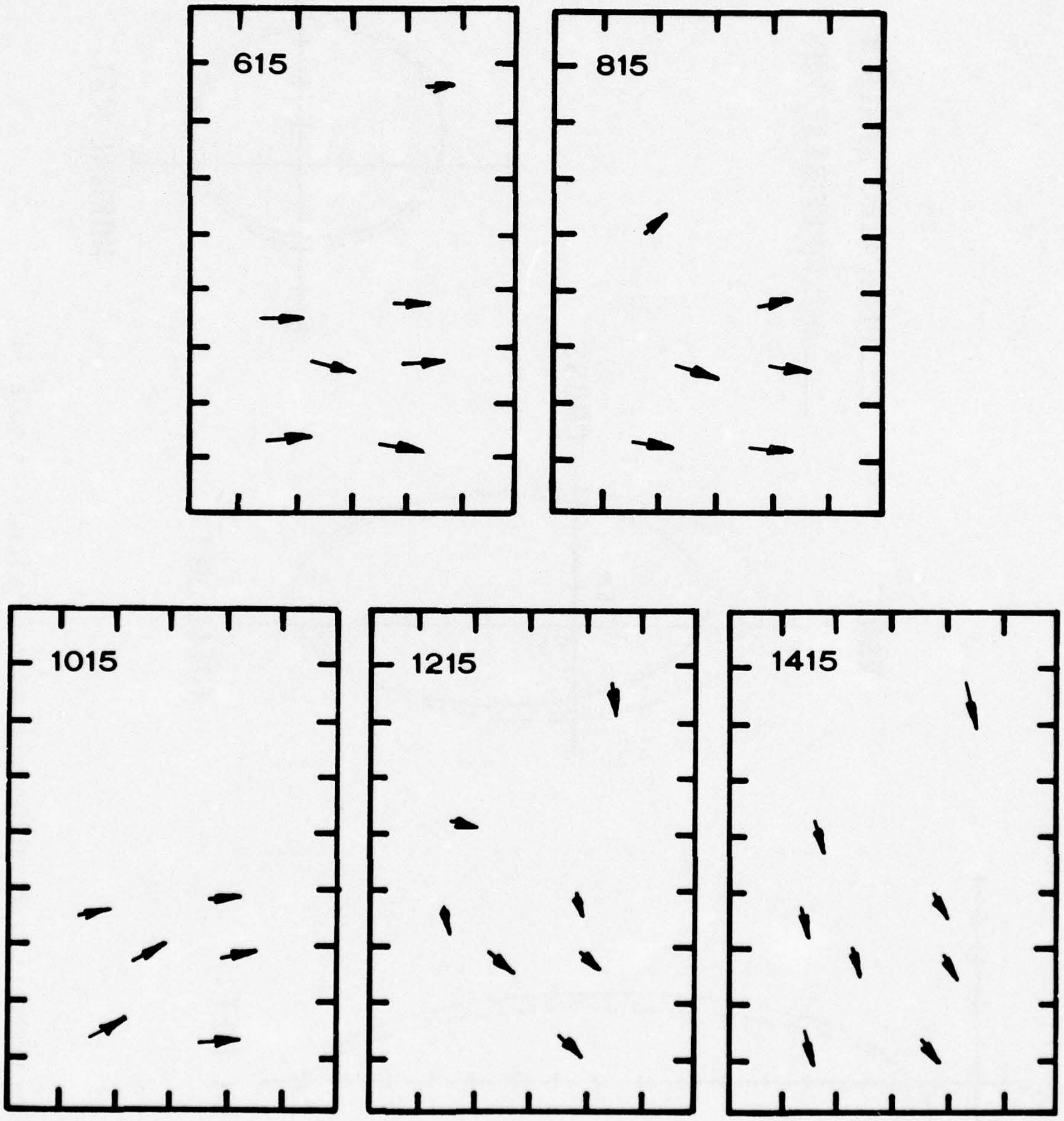

Figure 4. Time trending wind vector field, 23 Nov 74. Zone 5 (1500-2000 m AGL) with vector origins at stations.

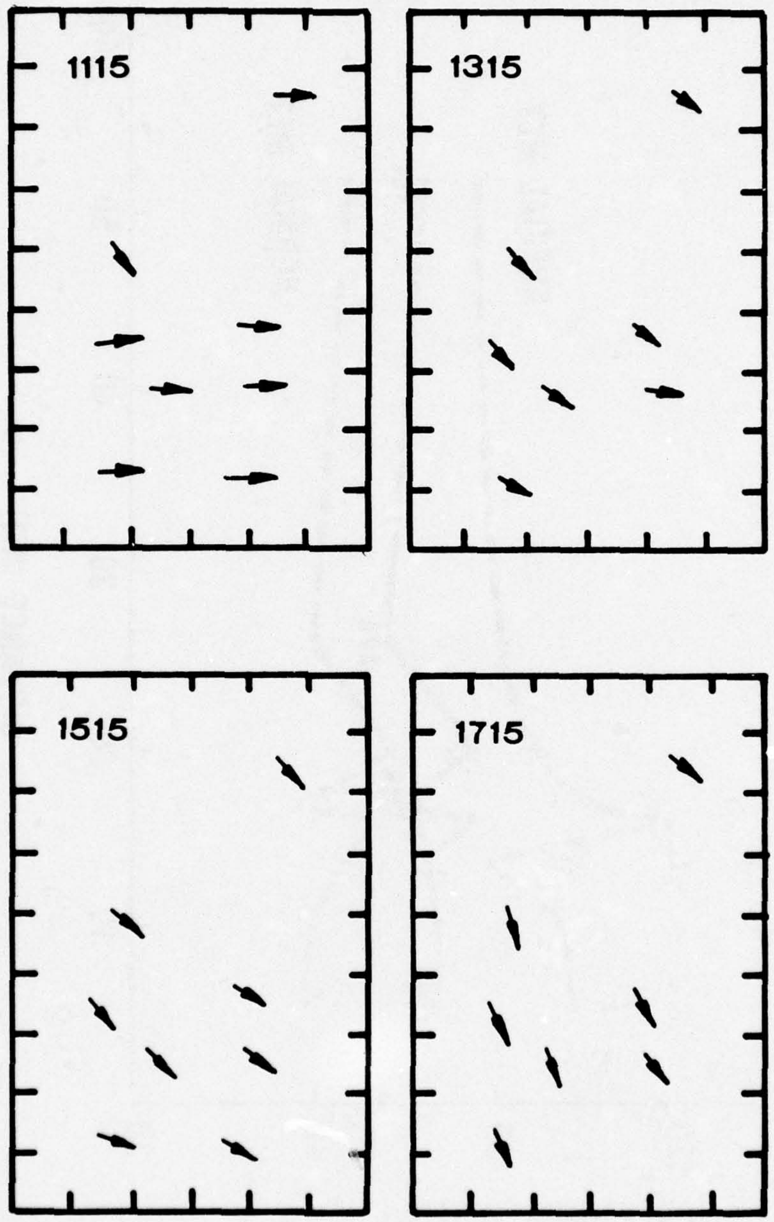

Figure 5. Time trending wind vector field, 5 Dec 74. Zone 5 (1500-2000 m AGL) with vector origins at stations.

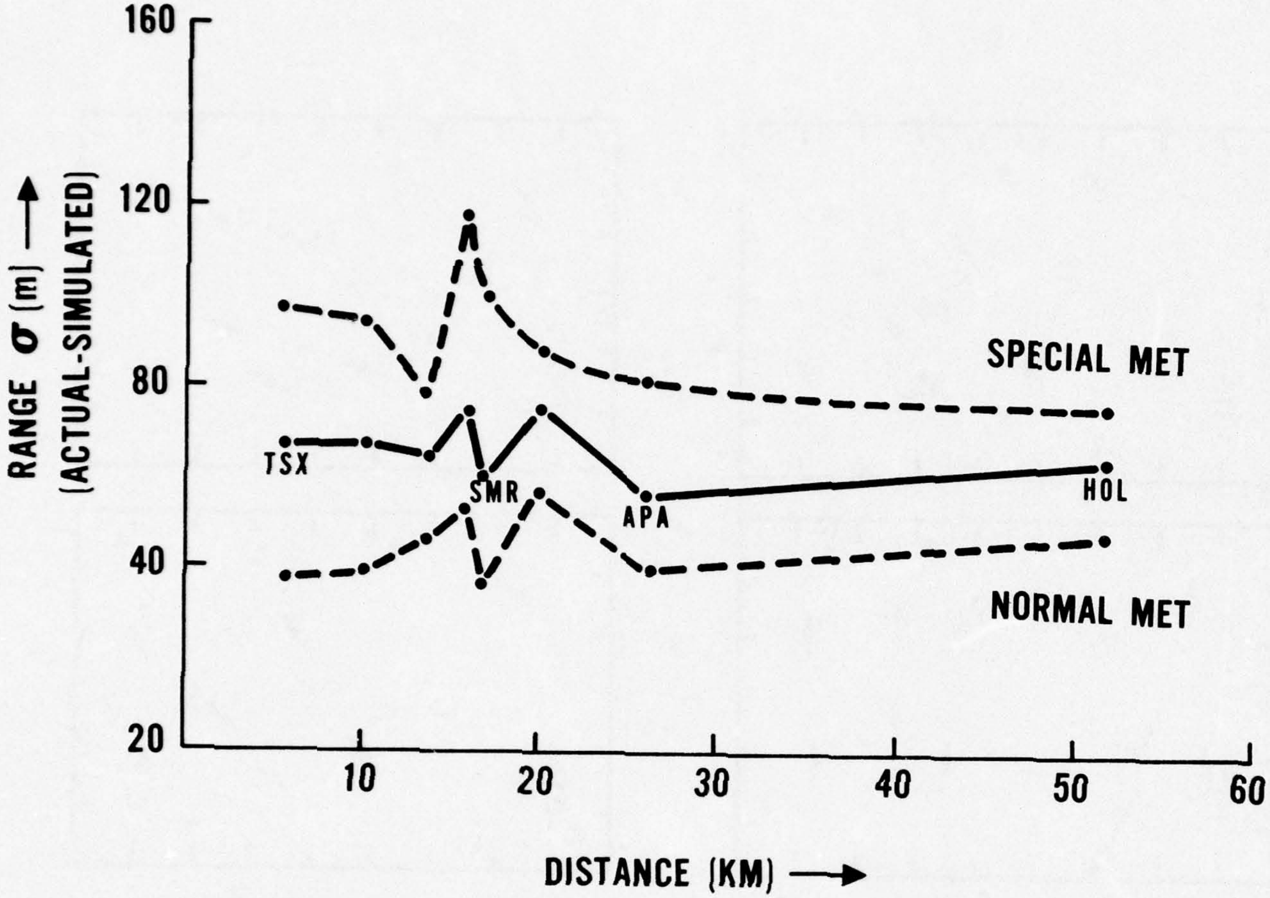

Figure 6. Space variability for 1-2 hr met.

variability curve of Figure 7 is self-explanatory. A comparison of Figure 7 with Figure 6 indicates the dominance of time variability over space variability insofar as ballistic effects are concerned. The SMR station is shown because it produced the best results of any single station (Method I) and was also located essentially upwind from the trajectory for most of the firings. Table 3 presents the combinations of soundings and firings utilized to obtain Figures 7 and 8.

CONCLUSIONS

The analysis of ballistic data from the PASS experiment indicates that the experimental errors were well within acceptable levels from the standpoint of ballistics. The application of two unsophisticated meteorology analysis algorithms to the data obtained from five meteorological stations failed to produce a practically significant decrease in the meteorological contribution to the total delivery error budget. In 68 of the 79 firing series examined, the error due to meteorology was less than 100 m range miss; and in fact, the dispersion for these 68 cases was small ($\sim$37 m range and $\sim$35 m deflection), which includes experimental error. This point should be examined closely in any future attempt to reduce meteorological disperions, since further investigation may reveal that the percentage of meteorological conditions wherein significant improvement is possible is too small to be of importance.

The idea that time variability of meteorology (in particular wind) is the major factor in large ballistic meteorology errors was corroborated and reinforced by the PASS results. The mode of simultaneous atmospheric soundings did not allow a study to be made of the value of soundings staggered in time from station to station over an interval of 2 hours, but the implication is clear that such a release schedule would go far toward reducing meteorological errors due to staleness. A central collection and disbursing system would therefore be useful in disseminating the most recent sounding to all batteries. In addition, such a system could make simple discrimination decisions such as separating stations from batteries where large terrain features might intervene, etc.

A final conclusion is that most of the advantage to be gained from a central disbursing system for artillery meteorological data would stem from the steady flow of fresh (½ hour to 1 hour old) meteorological messages to any battery, uninterrupted by relocation of a meteorological section, mechanical breakdown of the section, enemy action against the section, or any of the myriad hazards surrounding the prompt delivery of information from a given artillery meteorological section. ASL is currently making a detailed study of what may be achieved in increased artillery effectiveness from this viewpoint.

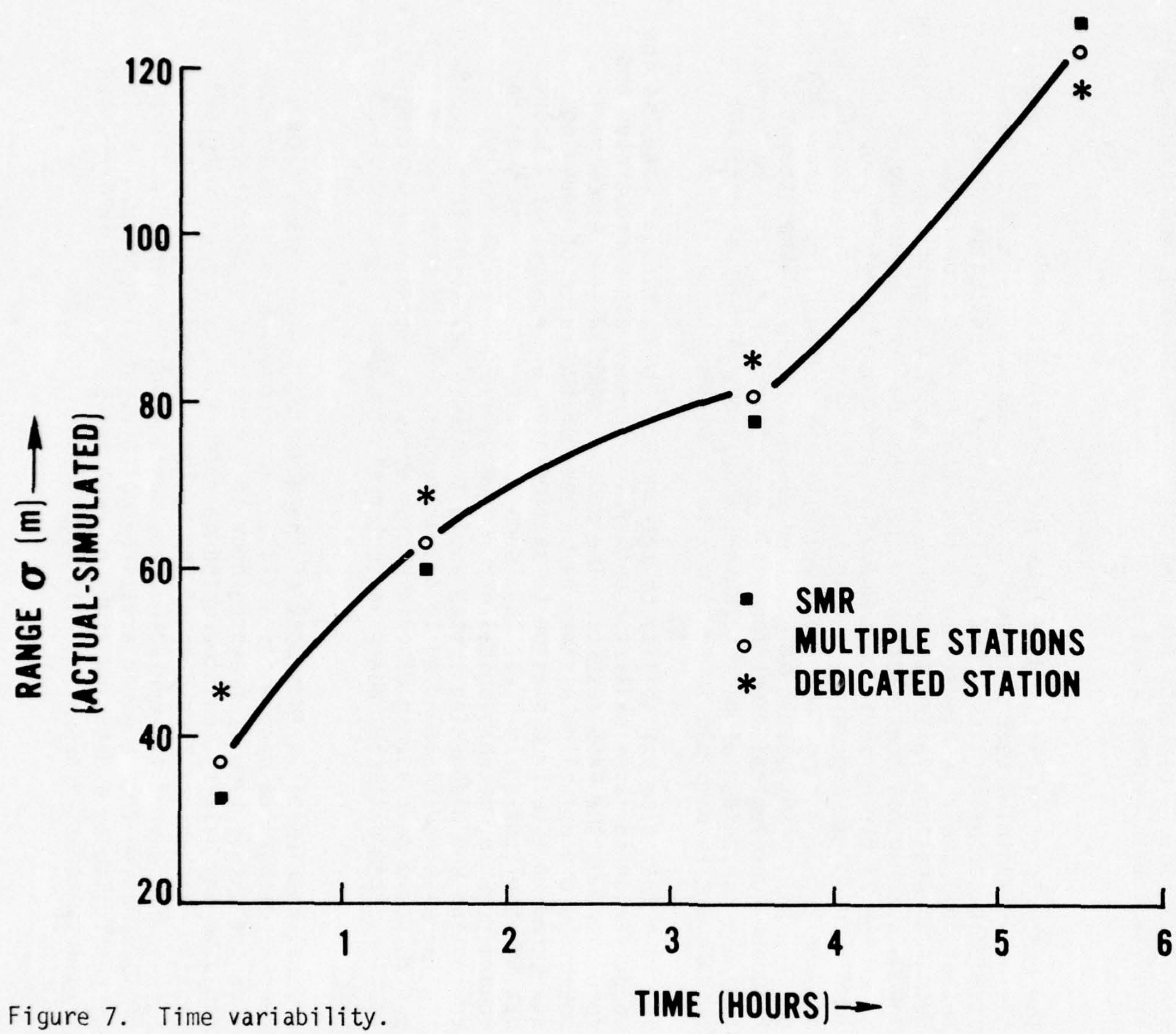

Figure 7. Time variability.

TABLE 3. SIMULATED IMPACTS VERSUS CORRESPONDING ACTUAL IMPACTS FOR VARIOUS METEOROLOGICAL AGES

Date	Meteorological Age (hr) 0.3	1	2	3	4	5	6
Nov 8		1400*					
	1500		X				
		1600		X			
	1700		X		X		
Nov 11		0600					
	0700		X				
		0800		X			
Nov 12		0530					
	0630		X				
		0730		X			
Nov 14		0500					
	0600		X				
		0700		X			
	0800		X		X		
		0900		X		X	
	1000		X		X		X
		1100		X		X	
	1200		X		X		X
Nov 15	0615		X				
		0715		X			
	0815		X		X		
		0915		X		X	
	1015		X		X		X
		1115		X		X	
	1215		X		X		X

Date	Meteorological Age (hr) 0.3	1	2	3	4	5	6
Nov 18	0630		X				
		0730		X			
	0830		X		X		
Nov 19		0630+					
		0830		X			
	0930		X		X		
Nov 20		1300					
	1400		X				
		1500		X			
	1600		X		X		
Nov 23		0730					
	0830		X				
		0930		X			
	1030		X		X		
		1130+		X		X	
	1230+		X		X		X
		1330		X		X	
	1430+		X		X		X
Nov 26		1330					
	1430		X				
		1530		X			
	1630		X		X		

Date	Meteorological Age (hr) 0.3	1	2	3	4	5	6
Nov 27		1030					
	1130		X				
		1230		X			
	1330		X		X		
Dec 2		0630					
	0730		X				
		0830		X			
	0930		X		X		
		1030		X		X	
	1130		X		X		X
		1230		X		X	
	1330		X		X		X
Dec 3		0700					
	0800		X				
		0900		X			
	1000		X		X		
Dec 5		1230+					
	1330+		X				
		1430+		X			
	1530+		X		X		
		1630+		X		X	
	1730+		X		X		X
Dec 7		0630					
	0730		X				
		0830		X			
	0930		X		X		
		1030+		X		X	
	1130		X		X		X
		1230		X		X	
	1330		X		X		X
		1430		X		X	
	1530		X		X		X

X - Simulated impacts
* - Time of actual firing
\+ - Firings with > 100 m range miss

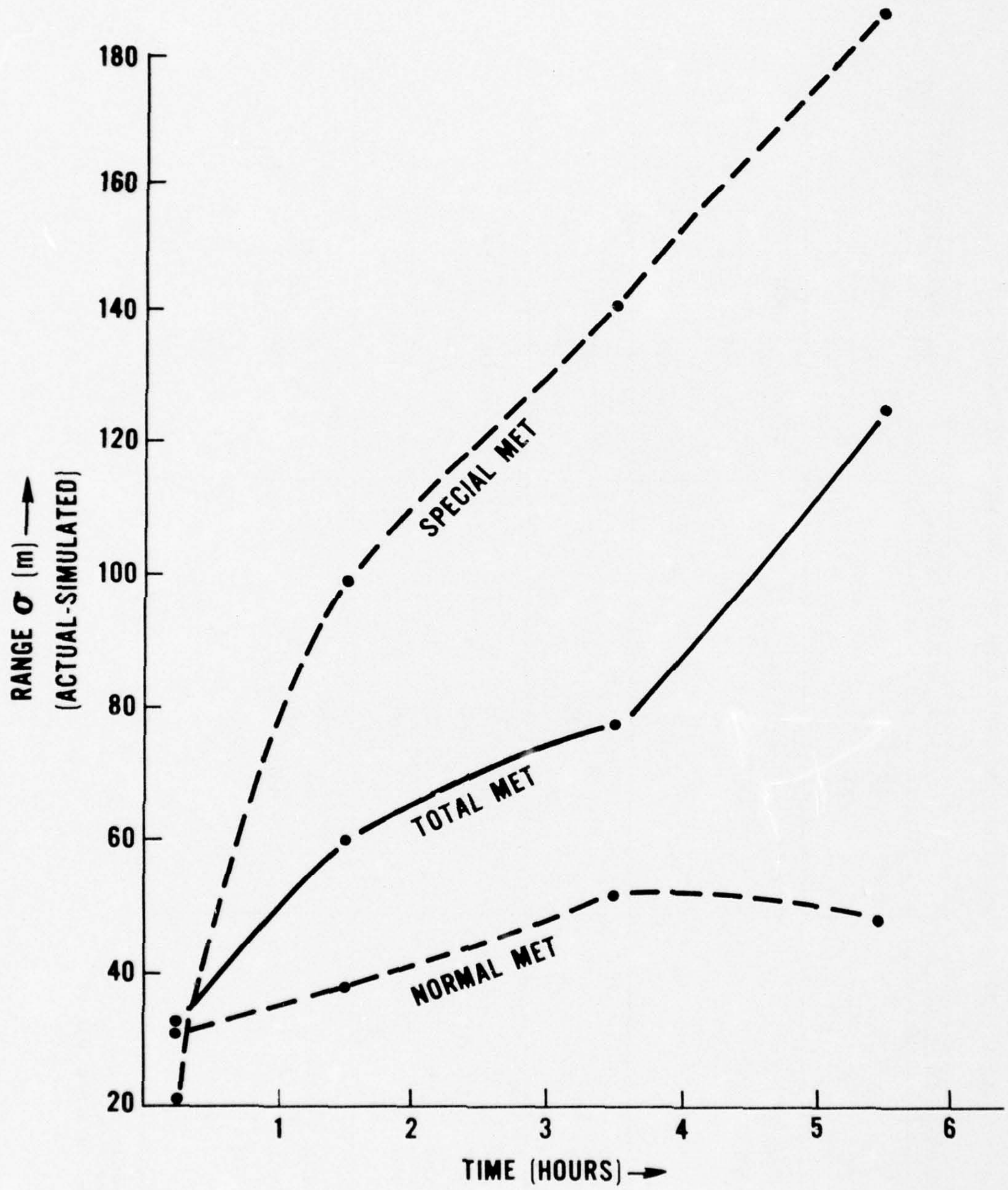

Figure 8. Time variability for SMR (generally upwind station).

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OMNITAB PASS DATA

APPENDIX. ALL HARDWARE PARAMETERS AND ACTUAL AND SIMULATED DISPLACEMENTS

MOSG	TIME	AZ	QE	M-MV	PT	SERIES
11081.2	1400.00	398.000	411.000	596.830	65.0000	1.00000
11082.2	1500.00	398.000	412.000	596.950	64.0000	2.00000
11083.2	1613.00	398.000	407.000	598.810	62.0000	3.00000
11084.2	1706.00	407.000	409.000	597.250	62.0000	4.00000
11111.1	607.000	394.000	443.000	593.620	50.0000	5.00000
11112.1	700.000	394.000	452.000	593.750	51.0000	6.00000
11113.1	800.000	394.000	440.000	592.360	48.0000	7.00000
11121.2	534.000	398.000	440.000	593.300	62.0000	8.00000
11122.2	630.000	399.000	439.000	595.540	59.0000	9.00000
11123.2	740.000	390.000	440.000	596.220	56.0000	10.0000
11141.1	500.000	394.000	428.000	595.650	63.0000	11.0000
11142.1	600.000	395.000	432.000	595.150	58.0000	12.0000
11143.1	700.000	395.000	428.000	600.050	60.0000	13.0000
11144.1	800.000	395.000	425.000	594.440	60.0000	14.0000
11145.1	900.000	395.000	432.000	593.300	53.0000	15.0000
11146.1	1000.00	396.000	430.000	592.570	54.0000	16.0000
11147.1	1100.00	396.000	434.000	590.830	55.0000	17.0000
11148.1	1200.00	395.000	437.000	593.370	52.0000	18.0000
11152.1	617.000	393.000	421.000	590.340	53.0000	19.0000
11153.1	715.000	393.000	421.000	590.500	49.0000	20.0000
11154.1	815.000	393.000	424.000	600.170	51.0000	21.0000
11155.1	915.000	393.000	408.000	592.430	52.0000	22.0000
11156.1	1016.00	392.000	414.000	597.100	51.0000	23.0000
11157.1	1128.00	391.000	416.000	593.340	51.0000	24.0000
11158.1	1215.00	391.000	417.000	592.430	49.0000	25.0000
11182.2	630.000	396.000	407.000	595.570	58.0000	26.0000
11183.2	730.000	396.000	404.000	596.730	57.0000	27.0000
11184.2	830.000	396.000	407.000	594.720	55.0000	28.0000
11191.1	630.000	386.000	417.000	594.160	62.0000	29.0000
11193.1	830.000	387.000	423.000	595.670	61.0000	30.0000
11194.1	930.000	388.000	422.000	592.160	61.0000	31.0000
11201.2	1302.00	402.000	411.000	597.430	70.0000	32.0000
11202.2	1400.00	401.000	415.000	597.400	68.0000	33.0000
11203.2	1500.00	401.000	411.000	598.340	75.0000	34.0000
11204.2	1600.00	401.000	414.000	596.360	70.0000	35.0000
11231.1	731.000	386.000	419.000	598.770	62.0000	36.0000
11232.1	830.000	387.000	414.000	597.540	59.0000	37.0000
11233.1	930.000	387.000	419.000	595.900	62.0000	38.0000
11234.1	1032.00	387.000	421.000	595.590	60.0000	39.0000
11235.1	1130.00	387.000	418.000	592.900	62.0000	40.0000
11236.1	1230.00	391.000	433.000	594.820	62.0000	41.0000
11237.1	1330.00	392.000	439.000	594.070	60.0000	42.0000
11238.1	1432.00	393.000	437.000	593.270	61.0000	43.0000
11261.2	1332.00	393.000	409.000	598.740	66.0000	44.0000
11262.2	1435.00	392.000	431.000	596.840	64.0000	45.0000
11263.2	1525.00	393.000	426.000	598.400	66.0000	46.0000
11264.2	1430.00	393.000	426.000	597.030	66.0000	47.0000
11271.2	1030.00	401.000	423.000	596.300	58.0000	48.0000
11272.2	1135.00	402.000	414.000	597.960	59.0000	49.0000
11273.2	1230.00	401.000	411.000	598.830	60.0000	50.0000

OMNITAB PASS DATA

MOSG	TIME	AZ	QE	M-MV	PT	SERIES
11274.2	1330.00	401.000	403.000	596.420	61.0000	51.0000
12021.2	632.000	396.000	423.000	603.170	56.0000	52.0000
12022.2	732.000	396.000	410.000	599.040	61.0000	53.0000
12023.2	830.000	397.000	420.000	600.700	61.0000	54.0000
12024.2	930.000	397.000	414.000	600.360	54.0000	55.0000
12025.2	1034.00	397.000	417.000	597.470	56.0000	56.0000
12026.2	1130.00	396.000	419.000	602.310	55.0000	57.0000
12027.2	1232.00	392.000	412.000	600.800	53.0000	58.0000
12028.2	1330.00	396.000	415.000	598.350	52.0000	59.0000
12031.2	700.000	397.000	422.000	602.190	60.0000	60.0000
12032.2	800.000	397.000	416.000	602.030	52.0000	61.0000
12033.2	900.000	397.000	415.000	599.500	52.0000	62.0000
12034.2	1000.00	397.000	417.000	597.510	48.0000	63.0000
12051.2	1230.00	391.000	407.000	601.780	63.0000	64.0000
12052.2	1330.00	390.000	414.000	602.430	60.0000	65.0000
12053.2	1435.00	388.000	421.000	603.220	60.0000	66.0000
12054.2	1530.00	388.000	413.000	603.230	62.0000	67.0000
12055.2	1630.00	387.000	418.000	599.720	62.0000	68.0000
12056.2	1730.00	389.000	425.000	599.630	62.0000	69.0000
12071.1	630.000	392.000	445.000	597.330	46.0000	70.0000
12072.1	730.000	393.000	431.000	598.400	46.0000	71.0000
12073.1	830.000	393.000	430.000	596.380	43.0000	72.0000
12074.2	930.000	394.000	431.000	600.540	42.0000	73.0000
12075.2	1032.00	394.000	425.000	593.200	42.0000	74.0000
12076.2	1130.00	394.000	429.000	600.730	44.0000	75.0000
12077.1	1230.00	393.000	425.000	597.670	48.0000	76.0000
12078.1	1334.00	393.000	425.000	597.810	50.0000	77.0000
12079.1	1430.00	394.000	426.000	594.740	49.0000	78.0000
12081.1	1534.00	394.000	429.000	591.860	52.0000	79.0000

OMNITAB PASS DATA

MO	TIME	METHOD I RA-RS	METHOD I CA-CS	METHOD II RA-RS	METHOD II CA-CS	METHOD III RA-RS	METHOD III CA-CS
11080	1400.	18.01	-10.06	36.85	-4.773	18.83	-4.728
11080	1600.	-47.79	2.475	-52.35	6.992	-46.81	7.827
11080	1613.	85.70	23.05	26.56	26.38	38.04	27.09
11080	1706.	19.04	42.48	-40.08	45.89	-15.67	46.33
11110	607.0	-23.56	27.74	-35.77	36.59	-39.10	38.68
11110	700.0	-24.59	38.34	-32.37	47.62	-36.90	49.86
11110	800.0	-33.78	38.13	-31.86	33.87	-24.94	35.87
11120	534.0	58.10	71.67	36.28	70.88	23.44	74.24
11120	630.0	-36.64	100.1	-58.54	101.3	-71.52	04.6
11120	740.0	-61.85	70.46	-64.71	64.96	-54.32	69.76
11140	500.0	11.75	32.97	9.022	24.58	6.276	26.26
11140	600.0	42.61	51.53	39.48	40.77	36.54	42.32
11140	700.0	58.22	33.78	47.41	28.79	57.93	34.04
11140	800.0	19.16	38.90	4.066	36.16	23.01	38.00
11150	900.0	14.57	15.79	-9.119	19.05	17.83	20.14
11150	1000.	-62.99	12.71	-87.91	18.27	-57.68	21.35
11150	1100.	18.95	28.01	31.53	22.37	31.74	22.25
11150	1200.	-9.405	34.36	.5599	31.98	5.976	30.79
11150	617.0	63.51	8.151	69.38	-2.494	74.11	11.14
11150	715.0	10.28	41.62	-.5730	25.72	-.01489	30.11
11150	815.0	34.32	78.03	22.26	62.06	18.20	67.66
11160	915.0	29.22	16.90	2.539	7.026	13.35	12.80
11160	1015.	-1.357	15.72	-28.08	5.422	-20.24	5.658
11160	1128.	21.08	9.412	-17.19	7.077	-2.403	16.50
11160	1215.	45.36	20.23	6.836	17.90	21.16	26.92
11180	630.0	56.42	19.87	50.67	16.75	49.61	15.94
11180	730.0	42.92	45.43	30.82	43.63	24.52	44.77
11180	830.0	-7.781	42.20	-19.63	40.53	-31.29	40.29
11190	630.0	-166.0	35.05	-142.7	49.79	-149.4	50.57
11190	830.0	27.67	18.10	-11.08	9.726	-5.727	14.07
11190	930.0	23.68	-30.91	-14.22	-39.83	10.08	-29.51
11200	1302.	44.45	10.63	30.01	11.15	31.54	8.714
11200	1400.	41.06	28.74	27.22	29.19	28.22	26.71
11200	1500.	-28.03	-8.050	10.04	-6.603	11.18	-9.687
11200	1600.	-48.31	47.70	-10.49	49.13	-9.972	45.34
11230	731.0	-77.30	10.18	-90.44	22.51	-84.98	22.02
11230	830.0	-46.82	-42.59	-61.90	-30.54	-57.23	-31.21
11230	930.0	32.33	-62.58	-29.01	-53.44	10.53	-53.36
11230	1032.	26.31	-101.8	-33.48	-90.37	26.19	-88.81
11240	1130.	-180.6	-38.08	-133.6	-30.19	-124.5	-32.98
11240	1230.	-267.0	-76.10	-220.4	-69.95	-204.0	-59.82
11240	1330.	-31.24	-18.03	-21.42	2.231	-18.49	-8.144
11240	1432.	-118.5	-22.33	-109.5	-2.287	-84.60	.7220
11260	1332.	-33.81	-14.84	-60.83	-18.17	-68.86	-19.07
11260	1435.	-27.52	-4.508	-55.41	-9.660	-62.85	-10.18
11260	1625.	-25.95	-17.34	-37.55	-15.69	-8.697	-17.10
11260	1430.	-2.221	-61.25	-13.77	-59.84	36.73	-60.07
11270	1030.	12.60	-29.59	9.584	-30.72	-6.104	-30.18
11270	1135.	46.39	-14.10	42.00	-14.50	27.28	-14.16
11270	1230.	48.17	-12.95	27.61	-12.87	27.50	-17.22

OMNILAB PASS DATA

MO	TIME	METHOD I RA-RS	METHOD I CA-CS	METHOD II RA-RS	METHOD II CA-CS	METHOD III RA-RS	METHOD III CA-CS
11270	1330.	72.82	12.63	49.32	13.03	47.31	6.129
12020	432.0	2.510	39.65	-30.70	36.42	-22.55	42.68
12020	732.0	6.492	50.03	-37.37	47.29	-28.83	53.27
12020	830.0	63.95	75.31	29.39	64.93	38.01	68.05
12020	930.0	17.86	39.81	-14.91	29.44	3.261	32.56
12030	1034.	-17.21	-6.675	-43.41	7.009	-62.21	6.214
12030	1130.	36.87	40.37	11.60	52.95	-10.34	53.12
12030	1232.	11.54	23.52	-15.80	22.33	-11.16	25.53
12030	1330.	18.46	33.94	-9.395	32.72	-9.081	32.73
12030	700.0	7.234	-8.913	-13.29	-10.39	-9.380	-12.44
12030	800.0	7.229	10.04	-12.87	8.766	-9.017	6.741
12030	900.0	19.44	1.652	14.57	.5780	22.51	3.113
12030	1000.	29.16	-2.799	24.70	-3.778	26.95	-2.000
12050	1230.	-187.1	-16.22	-234.0	-13.84	-233.6	-8.925
12050	1330.	-158.5	-8.995	-206.6	-5.975	-203.8	-.9600
12050	1435.	-77.14	-21.22	-101.1	-11.78	-105.6	-.5280
12050	1530.	-89.06	-17.20	-114.8	-7.724	-105.8	-4.200
12060	1430.	-136.3	9.787	-131.4	8.141	-141.5	14.32
12060	1730.	-172.4	13.88	-166.4	11.81	-164.2	18.67
12070	430.0	-34.14	33.93	-32.76	33.96	-29.27	36.16
12070	730.0	-24.21	-8.166	-27.53	-5.688	-22.36	-4.304
12070	830.0	-15.20	-3.004	-9.728	-8.693	-8.650	-5.027
12070	930.0	-32.35	-5.929	-24.40	-11.30	-29.30	-5.148
12080	1032.	118.8	21.18	106.2	22.55	115.2	21.88
12080	1130.	39.19	-10.05	26.17	-9.245	31.45	-10.77
12080	1230.	-61.49	-19.13	-45.42	-11.73	-31.15	-12.29
12080	1334.	-59.93	-31.60	-43.88	-24.19	-41.14	-25.91
12080	1430.	-32.84	-42.87	-65.16	-30.38	-40.60	-27.30
12080	1434.	20.29	-47.89	-12.25	-34.75	-2.733	-33.07

OMNI AB PASS DATA

MD	TIME	RANGE	CROSS	SERIES
11081.2	1400.00	14097.6	198.500	1.00000
11082.2	1500.00	14054.1	212.400	2.00000
11083.2	1613.00	14031.9	234.300	3.00000
11084.2	1706.00	13959.3	253.600	4.00000
11111.1	607.000	14003.6	281.400	5.00000
11112.1	700.000	14163.2	299.200	6.00000
11113.1	800.000	13942.7	262.700	7.00000
11121.2	534.000	14080.7	264.600	8.00000
11122.2	630.000	14034.0	294.400	9.00000
11123.2	740.000	14051.5	285.200	10.0000
11141.1	500.000	13999.3	262.600	11.0000
11142.1	600.000	14085.5	285.300	12.0000
11143.1	700.000	14166.0	279.100	13.0000
11144.1	800.000	13909.1	272.300	14.0000
11145.1	900.000	13996.4	249.100	15.0000
11146.1	1000.00	13363.5	242.100	16.0000
11147.1	1100.00	13962.8	253.300	17.0000
11148.1	1200.00	14053.8	266.400	18.0000
11152.1	617.000	13955.1	249.800	19.0000
11153.1	715.000	13911.5	280.700	20.0000
11154.1	815.000	14269.7	331.100	21.0000
11155.1	915.000	13757.7	279.300	22.0000
11156.1	1015.00	13974.3	288.700	23.0000
11157.1	1124.00	13913.3	295.900	24.0000
11158.1	1215.00	13929.5	306.700	25.0000
11182.2	630.000	13972.2	240.400	26.0000
11183.2	730.000	13943.0	270.200	27.0000
11184.2	930.000	13893.3	268.100	28.0000
11191.1	630.000	13802.5	400.200	29.0000
11193.1	830.000	14011.7	338.500	30.0000
11194.1	930.000	13908.2	283.100	31.0000
11201.2	1302.00	13931.5	156.900	32.0000
11202.2	1400.00	14002.1	177.400	33.0000
11203.2	1500.00	13957.6	145.100	34.0000
11204.2	1600.00	13936.8	201.700	35.0000
11231.1	731.000	14013.7	378.200	36.0000
11232.1	830.000	13917.5	317.500	37.0000
11233.1	930.000	13942.1	283.400	38.0000
11234.1	1032.00	13965.2	246.400	39.0000
11235.1	1130.00	13732.9	249.300	40.0000
11236.1	1230.00	13968.6	228.300	41.0000
11237.1	1330.00	14082.0	262.600	42.0000
11238.1	1432.00	13937.2	255.200	43.0000
11261.2	1332.00	13673.7	238.100	44.0000
11262.2	1435.00	14068.6	275.500	45.0000
11263.2	1525.00	13960.6	250.900	46.0000
11264.2	1630.00	13945.0	205.200	47.0000
11271.2	1030.00	14117.7	126.300	48.0000
11272.2	1135.00	14029.0	135.700	49.0000
11273.2	1230.00	14018.4	155.000	50.0000

OMNITAB PASS DATA

MO	TIME	RANGE	CROSS	SERIES
11274.2	1330.00	13822.1	170.300	51.0000
12021.2	632.000	14198.5	269.200	52.0000
12022.2	732.000	13805.6	270.000	53.0000
12023.2	830.000	14092.7	286.700	54.0000
12024.2	930.000	13927.8	247.700	55.0000
12025.2	1034.00	13876.9	228.800	56.0000
12026.2	1130.00	14110.9	279.500	57.0000
12027.2	1232.00	13938.1	252.800	58.0000
12028.2	1330.00	13930.9	263.400	59.0000
12031.2	700.000	14103.5	213.200	60.0000
12032.2	800.000	13992.1	228.000	61.0000
12033.2	900.000	13921.4	216.900	62.0000
12034.2	1000.00	13909.8	212.400	63.0000
12051.2	1230.00	13742.2	303.600	64.0000
12052.2	1330.00	13917.0	320.200	65.0000
12053.2	1435.00	14079.7	337.000	66.0000
12054.2	1530.00	13928.9	331.800	67.0000
12055.2	1630.00	13883.7	336.000	68.0000
12056.2	1730.00	13944.2	346.700	69.0000
12071.1	630.000	14142.7	315.500	70.0000
12072.1	730.000	13960.2	259.900	71.0000
12073.1	830.000	13927.6	245.800	72.0000
12074.2	930.000	14049.6	248.800	73.0000
12075.2	1032.00	13906.0	271.100	74.0000
12076.2	1130.00	14112.0	252.300	75.0000
12077.1	1230.00	13931.8	242.300	76.0000
12078.1	1334.00	13937.4	230.000	77.0000
12079.1	1430.00	13893.4	217.600	78.0000
12081.1	1534.00	13915.5	212.500	79.0000

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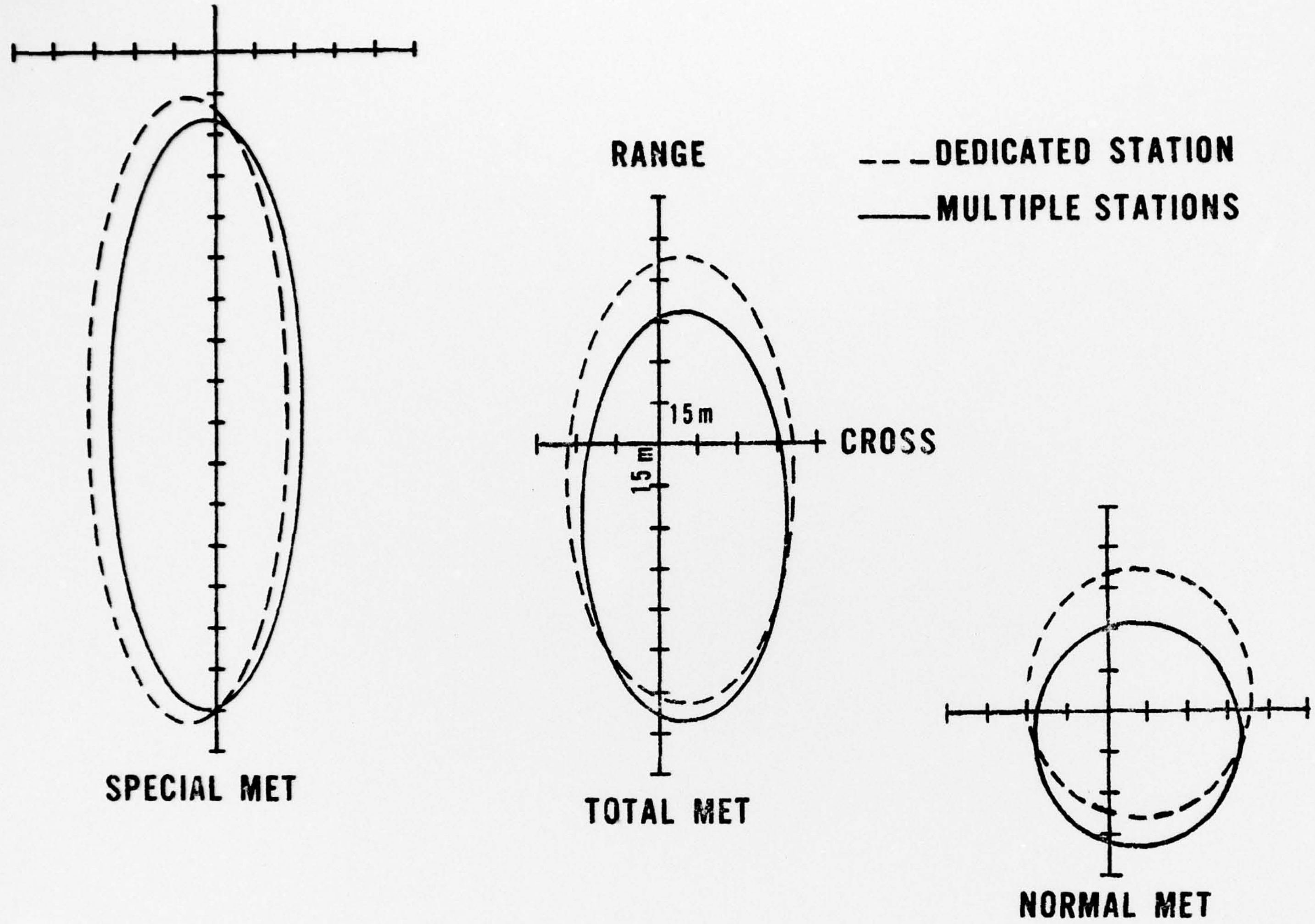

Figure 3. One probable error difference eclipse (actual - simulated).